# Equivalent circuit model and capacitance-voltage spectroscopy of matrix-assisted pulsed laser evaporated conjugated polymer thin-film solar cells

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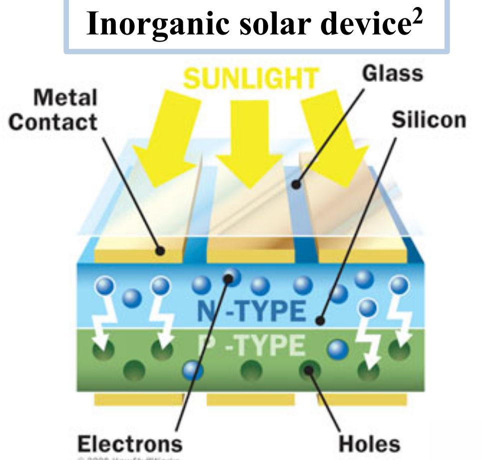
## Introduction

Polymer based organic optoelectric devices are a critical area of research because of their potential to be a cheaper and more flexible alternative to their inorganic counterpart. Using resonant infrared matrix-assisted pulsed laser evaporation (RIR-MAPLE), bulk hetereojunction thin-film solar cells were grown, modeled and characterized in the following sample sets:

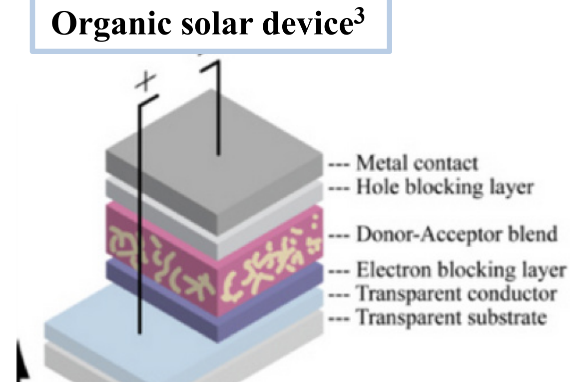
- **Deposition temperature study:** P3HT:PCBM – 1:1.5; 1,2,4-Trichlorobenzene (TCB) and Titanium oxide (TiOx) with varying deposition temperature (Uncontrolled ~ 10°C, 75°C, 150°C ), annealed at 140°C.
- **Primary solvent study:** P3HT:PCBM -1.5:1, annealed at 150°C with varying primary solvents including TCB, 3',5,5'-Tetramethylbenzidine(TMB), Chlorobenzene (CB) and 1,2 *Dichlorobenzene(ODCB).*

Methods of characterization for inorganic optoelectric devices have been well-established in literature[1]. Although different in structure, similar modeling and characterization of the bulk-heterojunction thin film solar devices give insight into the acceptor-donor interface by comparison.

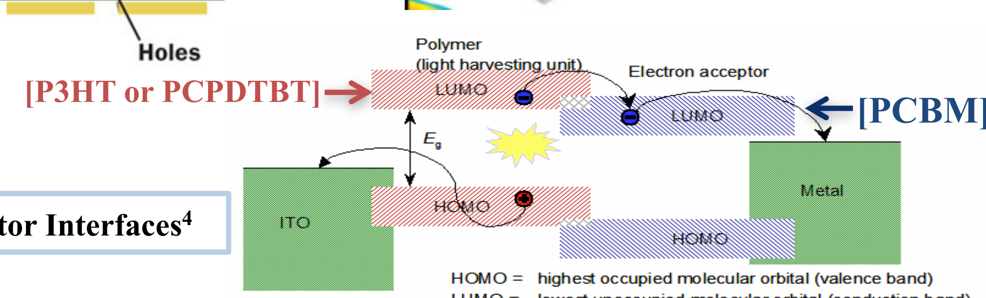
Inorganic solar device[2]




Organic solar device[3]




Donor-Acceptor Interfaces[4]

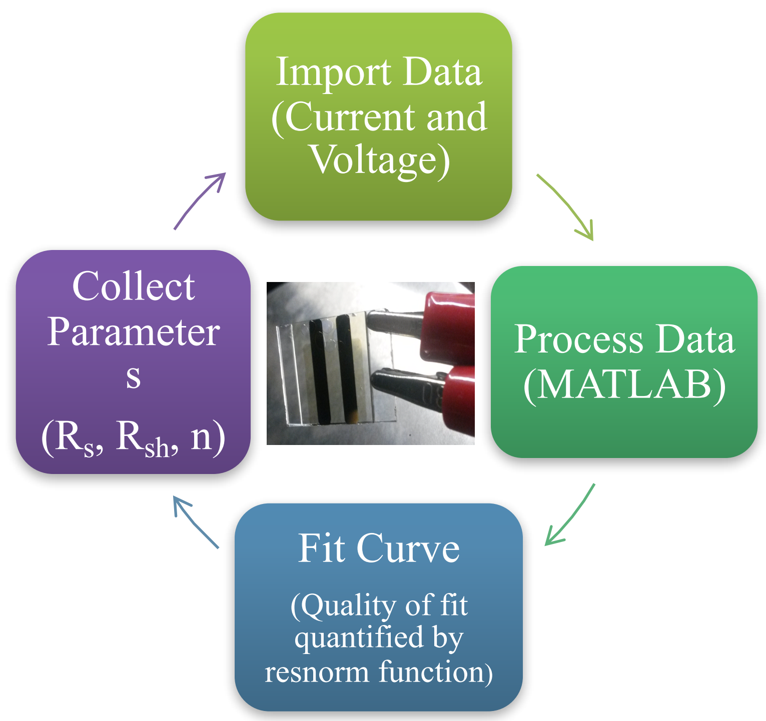



## Motivations

- Analyze effects of various bulk-heterojunction recipes on the specific parameters such as the ideality factor (n), shunt resistance ($R_{SH}$) and series resistance ($R_S$ ).
- Interpretation of built-in voltage ($V_{bi}$) and exploration of its contingences for organic bulk-heterojunction versus inorganic photovoltaic devices.
- Explore what capacitance spectroscopy on various sets of organic photovoltaic devices tell us about the $V_{bi}$.
- Investigate how is $V_{bi}$ a critical part of RIR-MAPLE grown solar.

## Methods

**1) Equivalent Circuit Model**




**2) Capacitance – Voltage Spectroscopy**

Device area measured: 0.1cm$^2$

*Mott-Schottky Equation*

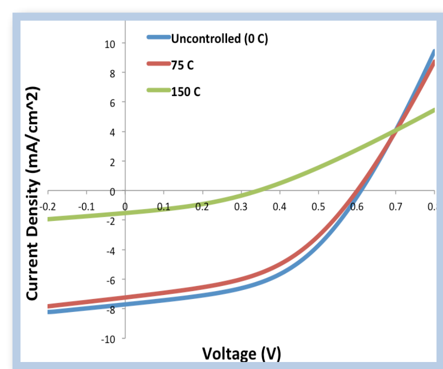
$$\boxed{C^{-2} = \frac{2(V_{bi} - V)}{q\varepsilon A^2 N_A}}$$

*Built – In Voltage ($V_{bi}$)*

$$\boxed{V_{bi} = \frac{kT}{q} \cdot \ln\left(\frac{N_D N_A}{n_i^2}\right)}$$

## Data and Results

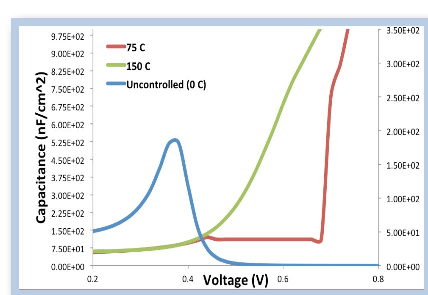
### *1.1 Deposition Temperature Study: J-V Plot and Characterization*

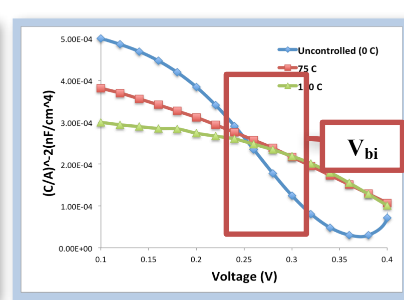


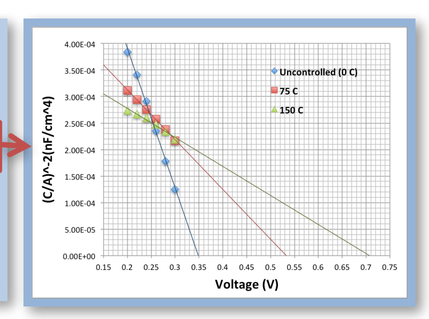

| Sample | n | $R_s$ ($\Omega$cm$^2$) | $R_{sh}$($\Omega$cm$^2$) | Quality of Fit |
|---|---|---|---|---|
| ~10° | 2.93 | 12.91 | 368.53 | 3.51E-07 |
| 75° | 3 | 13 | 295.02 | 8.20E-08 |
| 150° | 2.61 | 60.58 | 439.83 | 4.69E-07 |

| Sample | $V_{oc}$(V) | $J_{sc}$ (mA/cm$^2$ ) | FF | PCE (%) |
|---|---|---|---|---|
| ~10° | 0.6 | 7.4 | 0.48 | 2.15 |
| 75° | 0.6 | 7.2 | 0.45 | 1.94 |
| 150° | 0.35 | 1.52 | 0.34 | 0.18 |

### *1.2 Deposition Temperature Study: C-V and Mott-Schottky Plot Analysis*

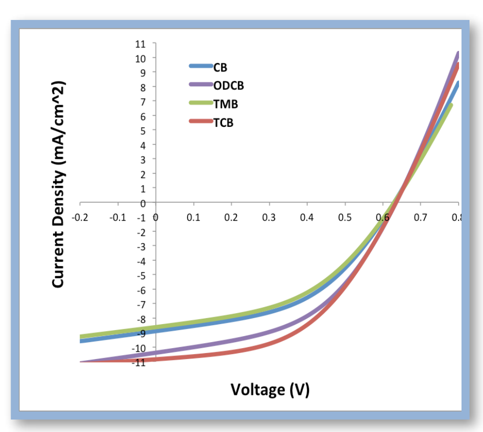



| Sample | $V_{bi}$ |
|---|---|
| ~10° | 0.35 |
| 75° | 0.53 |
| 150° | 0.71 |

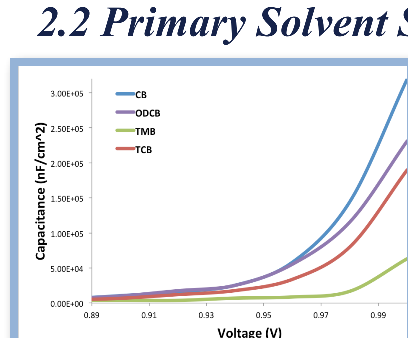
### *2.1 Primary Solvent Study: J-V Plot and Characterization*

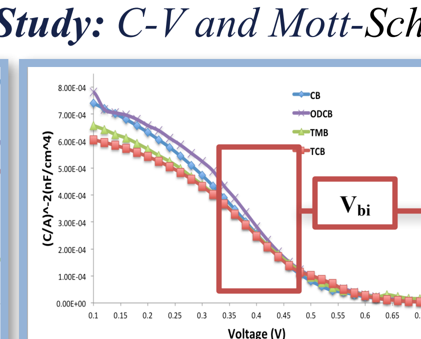


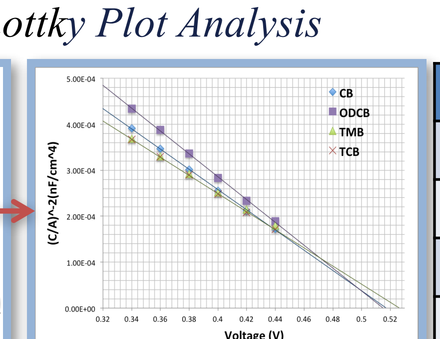

| Sample | n | $R_s$ ($\Omega$cm$^2$) | $R_{sh}$($\Omega$cm$^2$) | Quality of Fit |
|---|---|---|---|---|
| CB | 2.67 | 14.24 | 273.57 | 3.36E-06 |
| ODCB | 3.00 | 10.08 | 263.77 | 3.83E-06 |
| TCB | 3.00 | 11.90 | 587.94 | 7.92E-06 |
| TMB | 3.00 | 14.68 | 294.77 | 1.44E-06 |

| Sample | $V_{oc}$(V) | $J_{sc}$ (mA/cm$^2$ ) | FF | PCE (%) |
|---|---|---|---|---|
| CB | 0.63 | 8.897 | 0.459 | 2.572 |
| ODCB | 0.635 | 10.39 | 0.467 | 3.081 |
| TCB | 0.635 | 10.84 | 0.493 | 3.392 |
| TMB | 0.63 | 8.62 | 0.452 | 2.454 |

### *2.2 Primary Solvent Study: C-V and Mott-Schottky Plot Analysis*




| Sample | $V_{bi}$ |
|---|---|
| CB | 0.51 |
| ODCB | 0.51 |
| TCB | 0.53 |
| TMB | 0.51 |

## Discussion

- The **deposition temperature study** demonstrated a deposition at low temperatures yielded an optimal PCE. The lower values of $R_S$ and higher $R_{sh}$ are critical for the optimized PCE. The higher $R_S$ value in the 150°C sample is speculated to be due to the rough topography of the device that developed as a result of the high deposition temperature.
- The **primary solvent study** demonstrated excellent potential for future research into using solvents such as TCB in order to decrease $R_S$ .
- Although the $V_{bi}$ is an excellent tool for analyzing the exciton interfaces in the distinct active region of an inorganic photovoltaic device, further investigation into the meaning of what $V_{bi}$ does for bulk-heterojunction photovoltaic devices is still needed as PCE does not necessarily correlate to a higher $V_{bi}$ as would be expected.

## Future Research Possibilities

- Continue investigating the effects of various primary solvents (such as TCB) that yield higher PCE.
- Interpretation of $V_{bi}$ and exploration of its contingences for organic bulk-heterojunction versus inorganic photovoltaic devices.
- Further analysis on defining and characterizing $V_{MS}$ .
- Continue working with temperature deposition variations to analyze effects on bulk-heterojunction thin films photovoltaic devices.

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## Acknowledgements

This project was completed as part of the Research Experience for Undergraduates (REU) in the Electrical Engineering and Computer Science Department at Duke University. Support and guidance from the entire ADSR Research Group including Ryan M., Yuankai H., Becky R. and Eli L. was greatly appreciated.